

WHAT IS AN EXTRATIDAL HIGH WATER OR LOW WATER?

In tidal areas, an observed water level that exceeds the vertical limits of the predicted tide for a given location is called an **extratidal** water level. An **extratidal high water** is one that rises higher than the highest predicted tide and an **extratidal low water** is one that falls lower than the lowest predicted tide at that location.

The predicted or **astronomical tide** is the daily change in water level produced by the gravitational interactions of the earth, moon, and sun. Mathematical formulas allow the astronomical tides to be predicted years in advance for the familiar Tide Tables that list the predicted times and heights of the daily highs and lows. To specify a tidal height, however, requires a vertical reference called a **Tidal Datum**. Among those used in the United States are **Mean Higher High Water (MHHW)**, **Mean Lower Low Water (MLLW)**, and **Mean Sea Level (MSL)** (see <http://tidesandcurrents.noaa.gov>). The word 'mean' in this case refers to averages of observed water level taken over a specific 19-year period known as the **National Tidal Datum Epoch (NTDE)**, which currently includes the years **1983-2001**. While these datums are based on observations, two others are based on predictions: **Highest Astronomical Tide (HAT)** is the highest water level predicted and **Lowest Astronomical Tide (LAT)** is the lowest water level predicted relative to MSL over the NTDE. To make clear which series of years apply in their definition, the acronyms **HAT83** and **LAT83** are used in VIMS Tidewatch graphs.

Tides predicted relative to 1983-2001 MSL should never be higher than HAT83 or lower than LAT83. It follows that observed water levels that exceed either one of these levels in either direction are extratidal by definition. Since some predicted tides rise above MHHW and some fall below MLLW, no similar definition exists for these datums.

How do water levels become extratidal? There are two ways. A **storm surge** can push water levels higher or lower than expected due to the effects of wind stress and the change in barometric pressure. Water levels can also become extratidal through a **sea level anomaly**—a measure of the difference between short-term and long-term mean sea level. Sea level is dynamic and continually changing so understanding the difference is very important.

In the U.S., the National Oceanic and Atmospheric Administration (NOAA) defines long-term mean sea level (MSL) as the average of the hourly heights measured over the NTDE (other countries have their own definitions). Short-term usually refers to **monthly mean sea level (mmsl)**, another statistic that NOAA keeps track of. Tracking the difference between mmsl and MSL over a single year reveals important *seasonal* changes where mmsl is higher than MSL in some months and lower than MSL in others added to interannual change from one year to the next. Over tens of years, there are important *decadal* changes to reckon with and finally, there is *sea level rise* in the Chesapeake Bay area over the long term. Due to the latter, NOAA has to update the NTDE and revise its tidal datums about every 20 years or as needed.

As you can imagine, not a lot of time has to pass before we encounter sea level anomalies that matter. We don't want to see a large *positive* sea level anomaly (mmsl elevated well above MSL) just as a hurricane approaches the coast where we live. That's because the storm surge that comes with it will add to the mean water level that exists at the time—not the average that NOAA has worked up from measurements made more than a decade ago. This brings up another problem: like storm surge, the daily rise and fall in water level that we call the tide adds or subtracts from *time-local* sea level, not 1983-2001 MSL. To deal with this problem, a 30-day running mean of the **observed water level**—which we denote as **m30**—has been substituted for the usual calendar month in deriving time-local mmsl. The definition of sea level anomaly is then modified to become the difference m30-MSL (positive or negative) and m30 becomes the reference for the **astronomic tide** in the graphs at www.vims.edu/tidewatch. This allows all of the water level components to be shown in a snapshot of their behavior viewed in real time through the Tidewatch moving 30-day window.

You may occasionally notice in the tidewatch graphs that some of the astronomic highs exceed HAT (or that some of the astronomic lows fall below LAT). The reason this happens is because of the m30-MSL sea level anomaly as the preceding tutorial (hopefully) makes clear. If not, please read on!

In effect, the sea level anomaly is a correction that needs to be applied to tide predictions to account for short-term change in sea level. The formula for making this correction is:

$$\text{Astronomic Tide} = \text{Predicted Tide} + \text{Sea Level Anomaly}$$

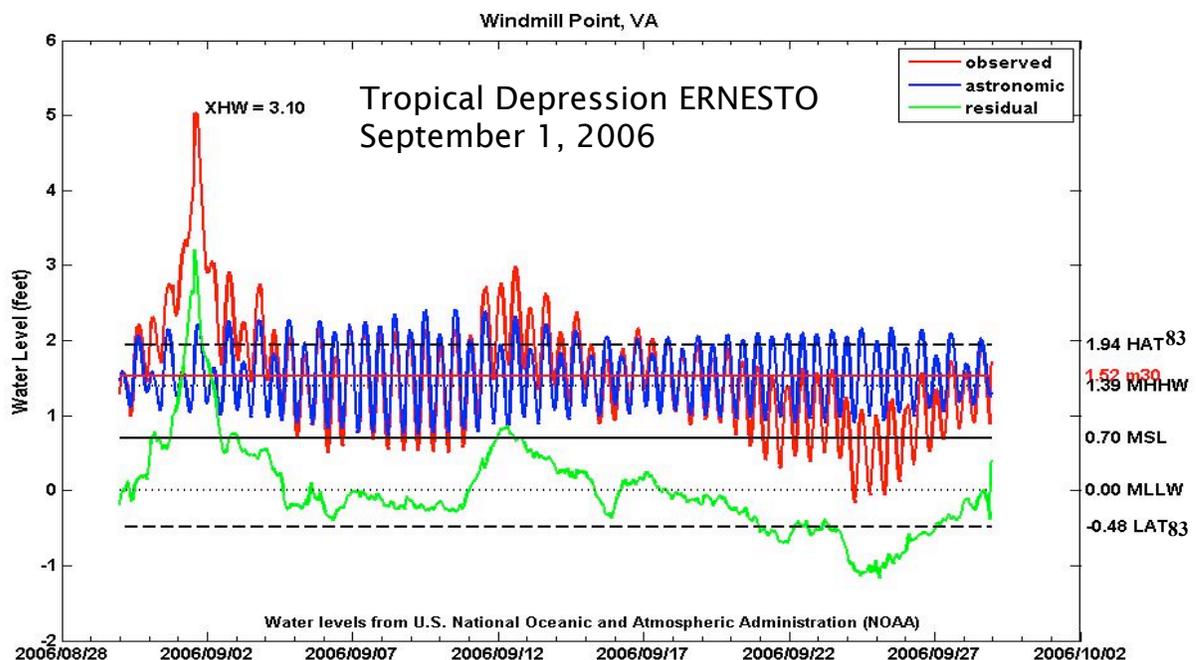
Having this correction allows another important formula to be written:

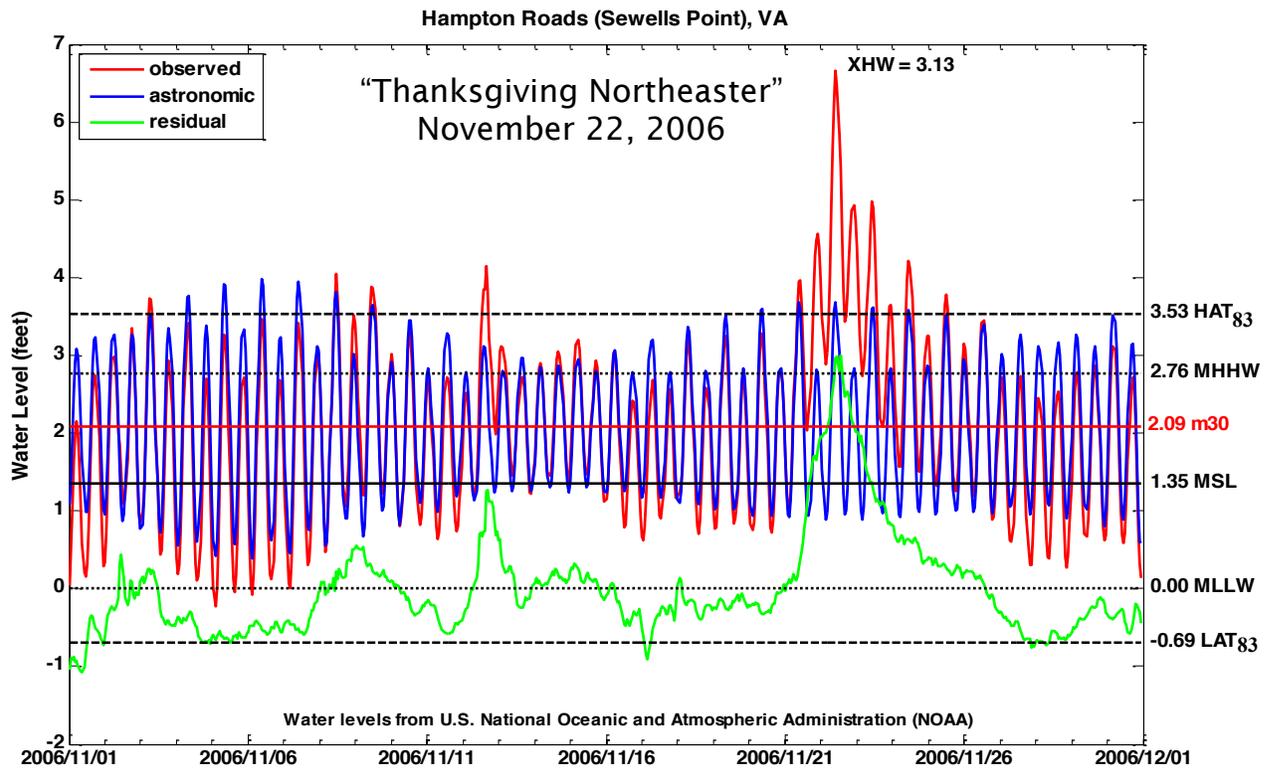
$$\text{Storm Surge} = \text{Observed Water Level} - \text{Astronomic Tide}$$

In words, the **residual** difference between observed and astronomic furnishes an estimate of the actual storm surge or meteorological tide recorded at a water level station. Caused by weather events, the meteorological tide can go up or down giving us extratidal water levels that go below LAT as well as above HAT.

The sea level anomaly, as we have defined it, represents a slow-acting, gradual change—change that is usually small but going on all the time. In contrast, the storm surge caused by a tropical storm or hurricane is often large and sudden, producing highly destructive **storm tides** after combining with the astronomic tide (worst case: spring tides, astronomic high near the storm surge peak with sea level elevated). As this game of roulette unfolds, the storm tide problem for coastal residents begins as water levels go extratidal and it gets bigger with every foot above HAT.

Extratidal High Water (XHW), the height in feet or meters above HAT datum, offers special advantages in comparing storm tides between locations with different tidal ranges (e.g., diurnal range = MHHW-MLLW difference). If we compare the storm tide below for Windmill Point, VA (range=1.39 ft) to a similar one at Hampton Roads (range=2.76 ft), we see XHW values that are about the same, yet the observed peak at Windmill Point is only 5 feet above MLLW as compared to 6.7 feet above MLLW at Hampton Roads. Nevertheless, the residents at Windmill Point experienced the pain of flooding as much, or more, than the people in Hampton Roads during these two events! Only XHW is a true index of flooding severity at these two locations.





A BRIEF SUMMARY AND EXPLANATION OF TERMS

- Extratidal High Water (XHW) and Extratidal Low Water (XLW) are observed water level extremes measured above the tidal datum HAT (XHW) or below the tidal datum LAT (XLW). These extremes occur in the presence of a weather-induced residual water level or ‘storm surge’ (observed water level minus the combination of astronomic tide and sea level anomaly). The astronomic tide referenced to m30, the average water level over the past 30 days, will not exceed HAT or LAT in the absence of a sea level anomaly.
- As used in the Tidewatch application, the sea level anomaly is the difference in elevation between m30 and the MSL tidal datum, the average water level over the current National Tidal Datum Epoch (presently 1983-2001). Defined this way, it is an index comparing short-term sea level with long-term sea level. Short-term sea level varies continually due to a combination of seasonal, interannual, and decadal change in water level as well as long-term sea level rise relative to the land.
- HAT83 is the elevation of Highest Astronomical Tide predicted during 1983-2001 for the station shown. No predicted tide referenced to MSL (or MLLW) should ever be higher than HAT83.
- LAT83 is the elevation of Lowest Astronomical Tide predicted during 1983-2001 for the station shown. No predicted tide referenced to MSL (or MLLW) should ever be lower than LAT83.
- MHHW, MSL, MLLW are the tidal datums of Mean Higher High Water, Mean Sea Level, and Mean Lower Low Water as defined by NOAA/NOS for the 1983-2001 National Tidal Datum Epoch (See <http://tidesandcurrents.noaa.gov>).